SENR Research with Distinction Program

The effect of Lake Erie algal blooms on Emerald Shiner

(*Notropis atherinoides*) visual morphology

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Abstract

Due to recent increases in agricultural runoff, Lake Erie has been experiencing harmful algal blooms (HABs) with rising severity. The runoff carries excess Phosphorus which is a limiting nutrient in freshwater and a main ingredient in agricultural fertilizers. This nutrient increase has been found to promote large blooms of *Microcystis* cyanobacteria, or blue-green algae, with the most recently severe blooms occurring in 2013-2015. HABs can negatively impact ecological health; for example, algal turbidity (suspended particles found in water) reduces the light available to aquatic species, resulting in impaired vision and ability to detect predators and prey. The objective of this study was to determine if there are differences in visual morphology between cohorts of Emerald Shiner (*Notropis atherinoides*) that experienced different levels of HABs during development. I predict that a more severe HAB will result in larger eyes, which, based on previous studies of fish in turbid water might help the fish see better under reduced available light conditions. Emerald Shiner were chosen because they are essential for energy transfer to economically important fish, such as Walleye (*Sander vitreus*) in Lake Erie and they have relatively short life spans. I analyzed the visual morphology of individual shiners (n=90) collected in 2013, 2014, and 2015 to determine the potential impact of increased algal turbidity. Visual morphology refers to the eye size and size of the optic lobe in the brain. The brain and left eye were removed from each fish, photographed under a stereomicroscope, and measured. Data collected includes the diameter of the total eye and pupil, and the axial length of the eye. The results of this study show that pupil diameter was significantly larger in fish collected one year after a severe HAB.

Introduction

Harmful algal blooms (HABs) severely impact the ecological landscape within Lake Erie. The blooms are caused by an increased dumping of phosphorus into the freshwater body. Phosphorus derives from agricultural fertilizer runoff from the surrounding watershed. Lake Erie's watershed is heavily farmed, with the highest concentration of toxic runoff coming in from the Maumee River running through Toledo (USGS 2000). Phosphorus will become a limiting nutrient within a freshwater body if there is a load over the maximum concentration the system can sustain (Kalff 2002). With a level exceeding the maximum concentration, a rapid increase of, for example, *Mycrocystis* cyanobacteria, or blue-green algae, can occur. This is referred to as an algal bloom. Freshwater systems are particularly vulnerable to algal blooms because their capacity of dilution is much less than larger marine bodies (Dudgeon et al. 2006). Increased water temperature will also promote the growth of cyanobacteria (Hense and Beckmann 2006). This combination of processes is currently occurring within the western basin of Lake Erie. The HABs have varied in severity over the years as conditions (e.g. Phosphorous load and temperature) have varied (Figure 1).

Algae blooms have severe impacts on ecological health and biodiversity. Cyanobacteria will consume oxygen within the freshwater body creating hypoxic or anoxic zones (i.e. low or no dissolved oxygen, respectively) (Eilola 2009). These depleted zones can lead to high mortality of fish through suffocation. Increased mortality is a large threat to biodiversity within freshwater systems. Freshwater contains over 10,000 species of fish and 40% of global fish diversity, however, only covers about 0.8% of the Earth's surface (Dudgeon et al. 2006). There is a decline of biodiversity within freshwater that is greater than most terrestrial systems because of the large amount of fish species in a small amount of surface area and due to human impacts on limited freshwaters (Sala et al. 2000).

Algal blooms also impact the turbidity level in the water. Turbidity is defined as suspended particles within a water column. There are two main types of turbidity: algal turbidity and sedimentary turbidity. This paper will focus solely on algal turbidity, also known as phytoplankton turbidity. The increase of cyanobacteria during an algal bloom will affect the light availability and color of the underwater visual environment within the freshwater system (Dugas and Frassen 2012). Phytoplankton turbidity scatters more light than sedimentary turbidity because the particles are smaller (Wotton 1994). The phytoplankton particles also absorb more light, resulting in a larger reduction of light (Wellington et al. 2010). This alteration can impact fish vision and so we might expect fish to respond to decreased vision by altering their visual morphology. Fish morphology in this context is defined as the size of the optic lobe in the brain and eye size. Previous research suggests that fish will allocate more resources to vision in dim light versus fish in brighter light (Pankhurst 1987). Another impact of turbidity is on prey consumption. Fish consumption is expected to decrease with an increase of phytoplankton turbidity (Wellington et al. 2010).

The study species for this project is the Emerald Shiner (*Notropis atherinoides*). Emerald Shiner were chosen because they are essential for energy transfer to economically important fish in Lake Erie, such as Walleye (*Sander vitreus*) and because they have a short life span (about three years). This allows for easy identification of developmental year (i.e. the year in which an individual hatched and developed), an important variable for this research. The diet of this common minnow species consists of insect larvae and zooplankton.

Dugas and Franssen (2012) preformed similar research with Red Shiner (*Cyprinella lutrensis*) in turbid (sedimentary) habitats. They collected shiners from areas with different turbidity concentrations and measured the total eye size of each individual fish. They found that Shiners in turbid habitats had larger eyes, which would increase their sensitivity to light and increase the success of visual feeding. Their study was a basis for the hypothesis and predictions of my research.

Hypothesis and Predictions

I hypothesize that the level or severity of the HAB during the development year will affect the visual morphology of Emerald Shiner cohorts. Based on this hypothesis, I predict that higher levels of HABs will be associated with larger eyes. The larger eye is expected to allow more light to enter the eye, compensating for the less light availability from a larger HAB.

Objective

The main objective of my study was to determine differences in visual morphology between cohorts of a common Lake Erie forage fish that experienced different levels of HABs during development. The Lake Erie forage fish studied is the Emerald Shiner.

Methods

Emerald Shiner were collected near Gibralter Island, Lake Erie by Chelsey Neiman and Tiffany Atkinson. The collections were made in summer 2014, 2015, and 2016. The fish were then preserved in ethanol or formalin and housed in the Gray

Aquatic Physiological Ecology Lab in Kottman Hall located at 2021 Coffey Rd. Columbus, Ohio. Thirty adults (n=30) were studied from each collection year, resulting in a total of 90 (n=90) adult Emerald Shiner measured. The 30 fish from each collection year are defined as one cohort, making a total of 3 cohorts studied.

Experimental set-up and design: A photo of each fish next to a ruler and identification tag was taken; each photo number was then recorded. Using the ruler, total length and standard length were measured in centimeters. Standard length is defined as the total length of the fish from the tip of the snout to the end of the caudal peduncle (i.e. excluding the tail fin). Fish mass was measured in grams. The left eye and whole brain were then extracted and preserved in a single tube with respective ethanol or formalin, depending on the chemical used for preservation, and an identification tag. After dissection, the sex of the fish was determined by examining the gonads. A stereomicroscope was used to perform three measurements for each collected eye. The three measurements were: total eye diameter, pupil diameter, and axial length. An example of each of these measurements are shown in Figure 2. Three measurements were taken for each diameter or length and the average was used for statistical analysis. The brains were not measured and will be used for a future study.

Statistics: Measurements were log transformed to improve normality. We used regression analysis to examine differences in the relationship between mass and standard length among cohorts. We performed ANCOVAs to test if there were differences in visual morphology between cohorts, for each eye size separately.

Standard length was used as a covariate in order to account for size differences between cohorts. If the ANCOVA was significant, then post hoc pairwise comparison tests were run to determine where the significance lies between the years.

Results

We used regression analysis to examine the length and weight of the individual shiners between cohorts. Fish caught in 2015 were longer and weighed more overall compared to those from 2014 and 2016 (Table 1, Figure 3). To analyze differences in visual morphology between the years, we used ANCOVA and post hoc comparisons using standard length as a covariate to account for size differences. All ANCOVA data is reported in Table 2 and all pairwise post hoc comparisons are reported in Table 3. Graphical analysis is represented in Figure 4. We found significant variation among the years for pupil diameter ($P = 0.050$). Significant post hoc pairwise differences were found between years 2014 and 2015 ($P = 0.022$) and years 2015 and 2016 ($P = 0.024$). We found marginal significance in total eye diameter among years ($P = 0.068$). From the post hoc comparison, there was marginal significance between the years 2014 and 2016 ($P = 0.064$). There was no difference in axial length among years ($P = 0.631$).

Discussion

My results suggest that the visual morphology of Emerald Shiner may be associated with the level of HABs during development. Fish collected in 2015, representing the fish that developed under the less severe 2014 HAB (Figure 1), were larger (length and weight) and had a smaller relative pupil diameter compared to the

2016 and 2014 cohorts. There was marginal significance for total eye diameter, with 2016 fish, those that developed under the most severe 2015 HAB (Figure 1), having slightly larger eyes. This information suggests that there is a stronger allocation of resources to eye and pupil diameter than body size for fish that develop under more severe HABs. Increased eye size may allow more light to enter the eye to compensate for reduced light availability. Axial length, which determines the focal length at which an organism can form an image of an object, was unchanged by the severity of HAB. With the presented results, we conclude a possible association between larger eyes and higher levels of HABs. This is consistent with similar results found from previous studies on small cyprinids in sedimentary turbidity (Dugas and Franssen 2012; Howland 2004).

The next step of this research study is to look at the relationship between visual morphology and sex of fish to determine if males and females have different responses to HABs. Another step is to perform measurements on collected brains, testing if visual centers in the brain (i.e. optic lobe size) also differ among severity of HAB. These two steps already have collected data and are only missing the proper analysis. A future direction for this research would be measuring the visual morphology of Emerald Shiner from decades past (i.e. 1980s, 1990s) along with analysis of Lake Erie satellite images for a long-term view of water quality change and vision. Studying the visual morphology trends throughout the years will help to determine whether the results presented in this study are a response to changing conditions or a trend occurring over time.

Acknowledgments

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Tables

Table 1. Length, mass, and regression analysis values for each Shiner cohort.

Cohort Year	Average Standard Length (cm)	Average Mass (g)	Slope of Regression Line	R^2 Value
2014	46.400	0.845	2.923	0.874
2015	58.700	2.346	2.902	0.857
2016	45.467	0.870	2.304	0.720

Table 2. ANCOVA results for eye measurements. **non-significant interaction term P>0.05. *non-significant interaction term P>0.10

	d.f.	F statistic	P-value
Eye Diameter			
Year	1,2	2.770	0.068*
log SL	1,86	17.750	<0.001
Pupil Diameter			
Year	1,2	3.099	0.050**
log SL	1,86	16.238	<0.001
Axial Length			
Year	1,2	0.464	0.631
log SL	1,86	13.112	<0.001

Table 3. Post hoc comparison P-values. **non-significant interaction term P>0.05. *non-significant interaction term P>0.10

	2014 and 2015	2014 and 2016	2015 and 2016
Total Eye Diameter	1.000	0.064*	1.000
Pupil Diameter	0.022**	0.895	0.024**
Axial Length	1.000	1.000	1.000

Figures

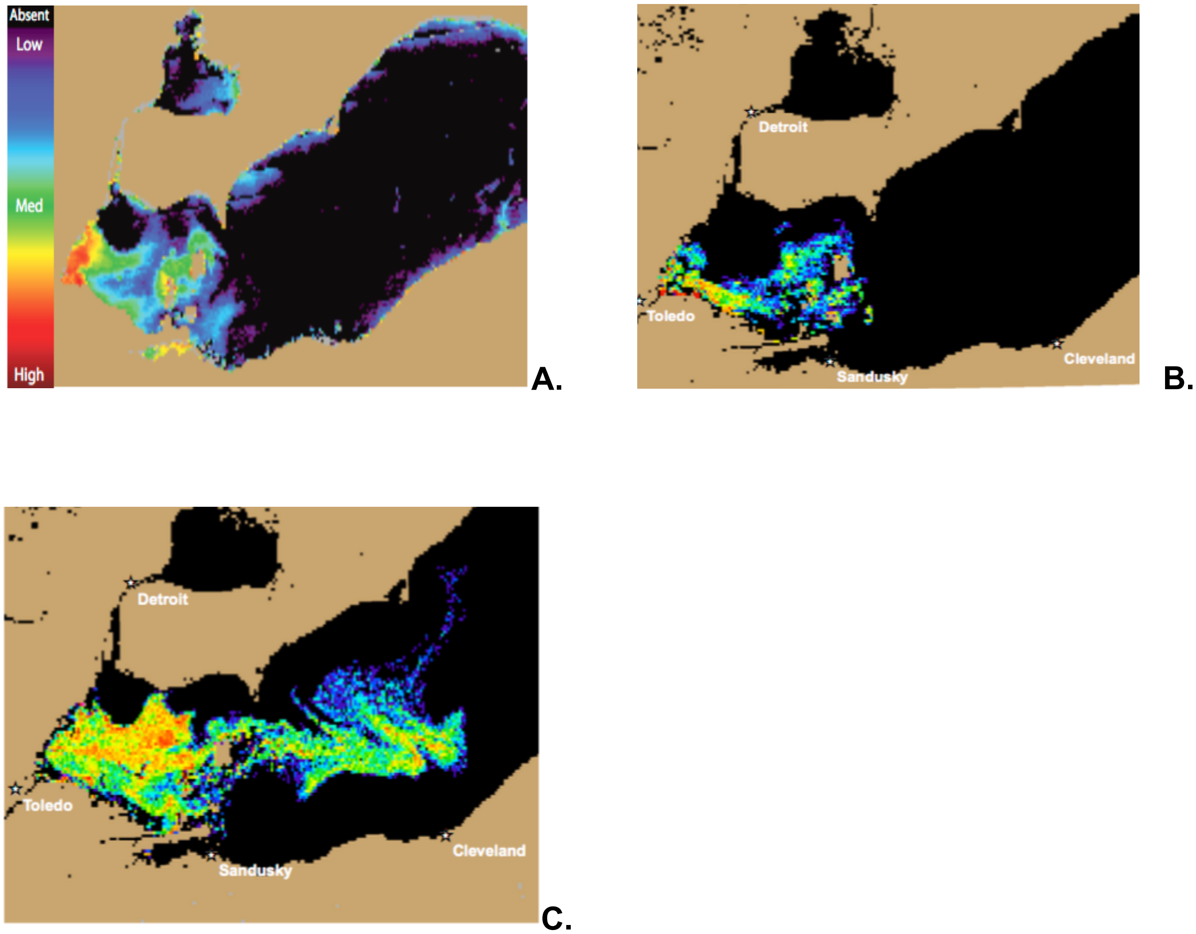
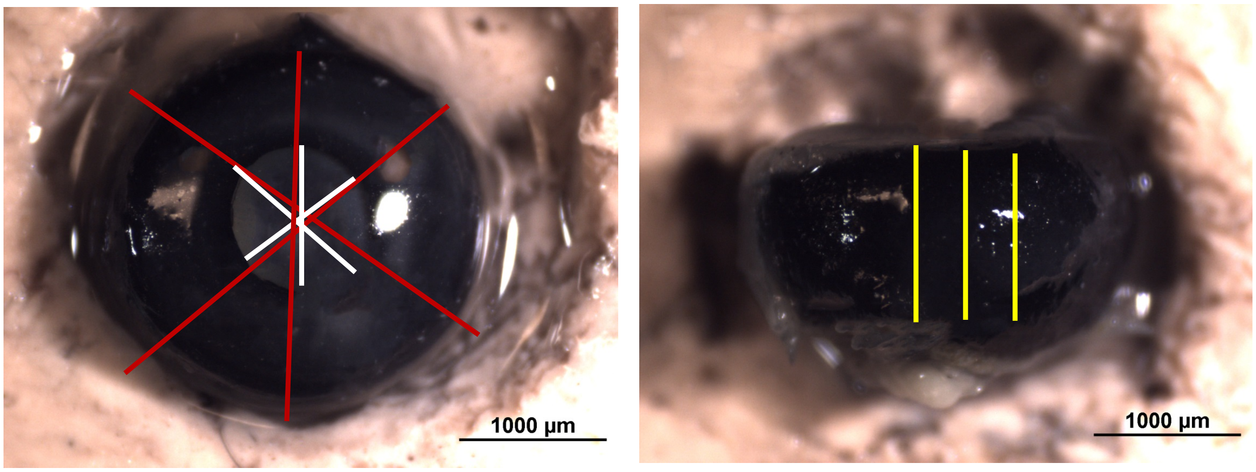


Figure 1. Satellite images of Lake Erie HABs during the years in which each cohort developed. Images are from NOAAs Lake Erie HAB tracker. Image A is the HAB from 2013, during which the 2014 cohort developed. Image B is the HAB from 2014, during which the 2015 cohort developed. Image C is the HAB from 2015, during which the 2016 cohort developed.



A. B.

Figure 2. (A) Front view and (B) axial view of extracted eye with replicated measurements of eye diameter (red), pupil diameter (white), and axial length (yellow) shown.

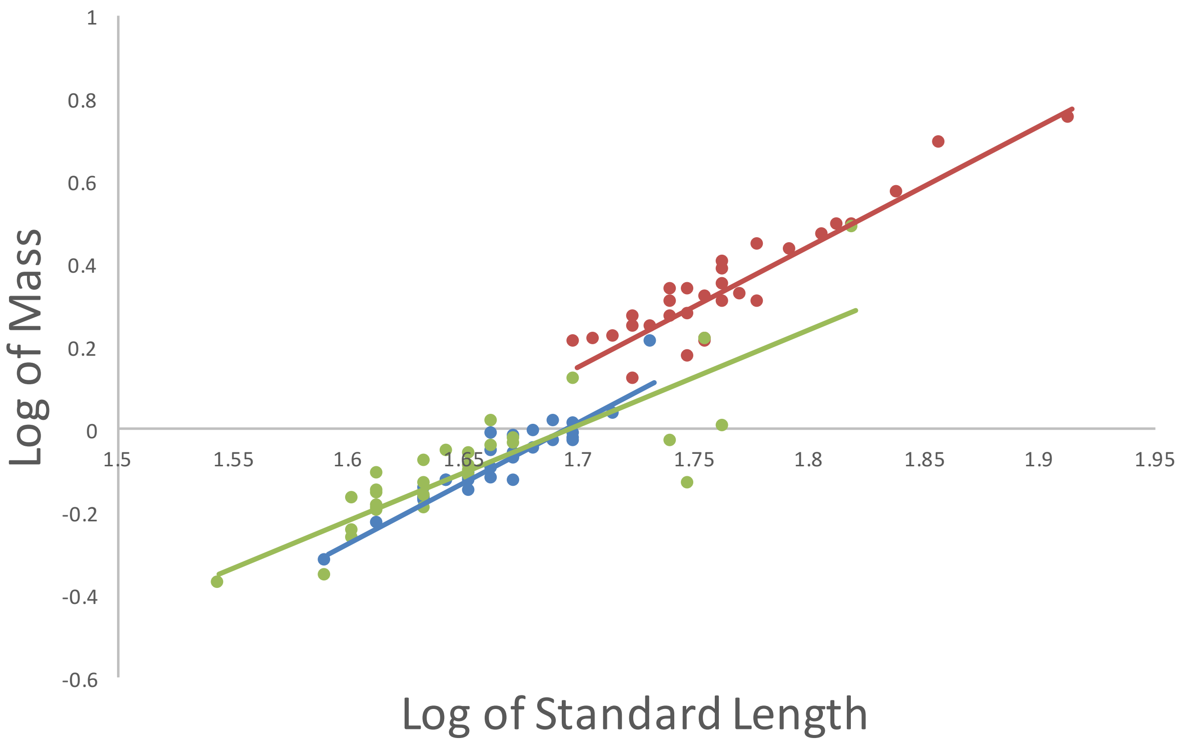


Figure 3. Regression of mass *vs.* standard length by cohort year (2014: blue; 2015: red; 2016: green).

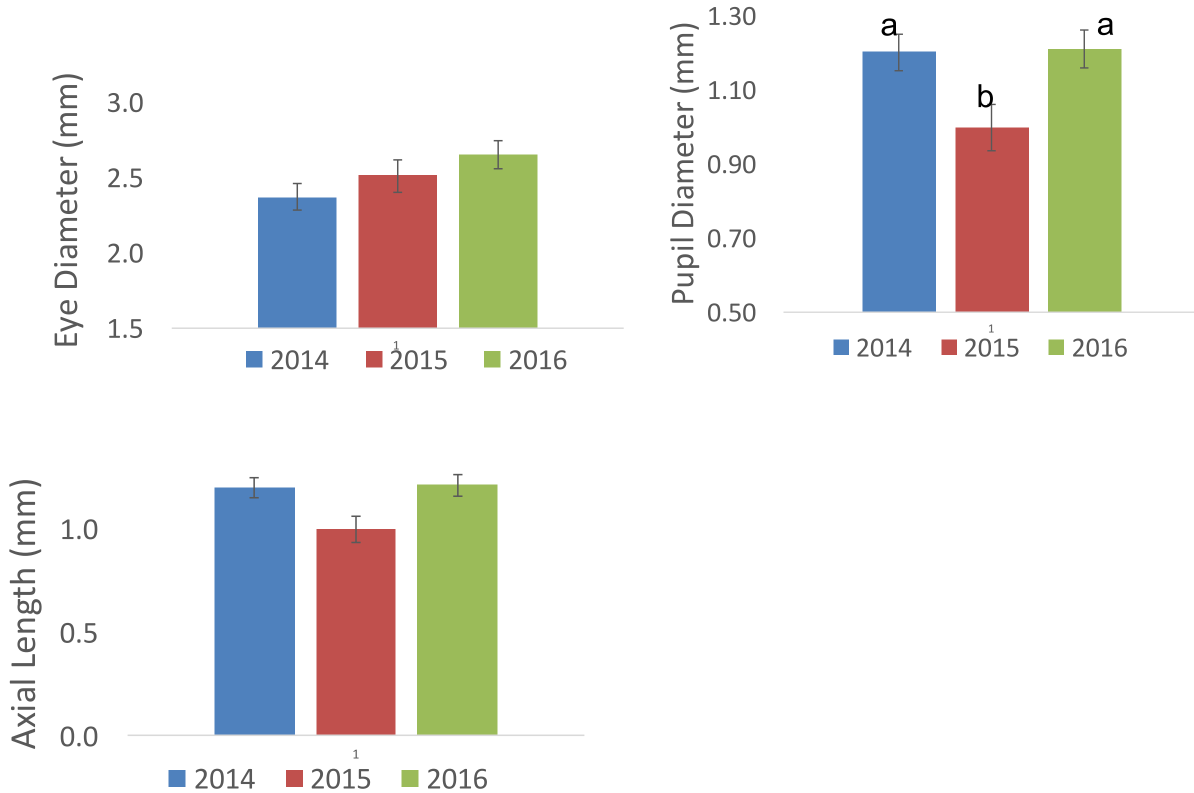


Figure 4. Mean eye size variables (± s. e.) across each cohort year. Significantly different post hoc tests indicated by different letters.